file
FM Multiplex

WAYNE UNIVERSITY
BOARD OF EDUCATION
DETROIT 1, MICHIGAN

COLLEGE OF LIBERAL ARTS
DEPARTMENT OF SPEECH

November 30, 1954

Mr. Cecil Bidlack
National Assoc. of Educ. Broadcasters
14 Gregory Hall
Urbana, Illinois

Dear Cecil:

Thank you for the copy of your letter from Murray Crosby on the subject of FM multiplexing. As I interpret the letter, we can expect little likelihood of FM multiplexing for the purpose we have in mind within the immediate future. I am still of the opinion that this general idea represents worthwhile potential opportunity for the NAEB, and for this reason would appreciate your sending me any further information that should come your way.

Very truly yours,

Paul

Paul B. Rickard

PBR:mf

RECEIVED
NAEB HEADQUARTERS
DEC 2 1954
AM PM
9 10 11 12 1 2 3 4 5 6

November 24, 1954

Mr. Murray G. Crosby, President
Crosby Laboratories, Inc.
Box 233, Robbins Lane
Hicksville, New York

Dear Mr. Crosby:

Thank you for your letter of November 22 and the reprint of your article on "FM Multiplexing."

I wrote because one of the Directors of NAEB thought that, by the use of multiplexing on some of our educational FM stations, it might be possible to create an educational FM network. This might replace, or at least supplement, the NAEB tape network for the distribution of programs in areas where there would be sufficient signal strength for networking. He felt, that by the use of multiplex it would also be possible to transmit one program locally and still repeat the network program to another station.

I believe that the cost of multiplexing equipment would also be a deterrent to its use by educational stations since Mr. Coulton estimated the multiplexing equipment might cost $5000 per station with another $2000 for test equipment. He would not estimate the cost of receiving equipment.

Since there are problems still to be solved as far as multiplexing is concerned, it might be better for us to survey the possibility of an FM network using existing facilities. If this proved workable and there was need for multiplexing, then we could proceed from this accomplishment. I can see that there would be problems of programming and coordination to be solved in addition to technical ones.

If you would care to make further comments on the basis of this additional information, I should be happy to have them.

Thank you for your interest.

Yours very truly,

Cecil S. Bidlack
Television Engineer

CSB:cp

Copy to Carl Menzer-WSUI

CROSBY LABORATORIES, INC.

BOX 233 • ROBBINS LANE • HICKSVILLE, N.Y.
Telephone: Hicksville 3-3191

22 November 1954

Mr. Cecil S. Bidlack, Television Engineer
National Association of Educational Broadcasters
14 Gregory Hall
Urbana, Illinois

Dear Mr. Bidlack:

In accordance with the request of your letter 12 November 1954, I am enclosing herewith a copy of the article I wrote regarding the use of FM multiplex for binaural transmission.

I gather that your usage of multiplex would not use the system for binaural transmission, but might apply two separate programs. Accordingly, perhaps I can give you a brief review of the status of such operation at this time.

At the present time, we are a bit unhappy with the status of the development of multiplex equipment. In the past, many laboratory demonstrations have been made which gave satisfactory operation. However, when we tried to reduce the equipment to a practical stage many problems appeared. When separate programs are applied, as distinguished from binaural transmission, the degree of cross-modulation between channels must be reduced to values far in excess of that necessary for binaural transmission. At present we are not satisfied with the levels of cross-modulation that we obtained on our existing equipment and we have invested so much in the development program so far that we have been forced to slow down the amount of effort we put into the project. We have tried to enlist the interest of other companies, who might be willing to finance the additional development work required, but so far have had no success. Most people look upon FM as a money-losing proposition no matter how you look at it.

The most economical multiplexing system would

apply only one additional channel. If additional channels are applied the equipment becomes more complex and expensive. We have applied as many as three additional channels successfully. The range of the multiplex channel is much less than that of the main channel and becomes still less as additional multiplex channels are added.

If you would care to give me further information as to your specific application of multiplexing, I would be glad to comment further.

Very truly yours,

CROSBY LABORATORIES, INC.

Murray G. Crosby

Murray G. Crosby, President

MGC/he
Enc. (1)

FOR INFORMATION OF ____________

CROSBY LABORATORIES, INC.
Box 233 • Robbins Lane
Hicksville, N. Y.

22 November 1954

Mr. Cecil S. Bidlack, Television Engineer
National Association of Educational Broadcasters
14 Gregory Hall
Urbana, Illinois

Dear Mr. Bidlack:

In accordance with the request of your letter 12 November 1954, I am enclosing herewith a copy of the article I wrote regarding the use of FM multiplex for binaural transmission.

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If you would care to give me further information as to your specific application of multiplexing, I would be glad to comment further.

Very truly yours,

CROSBY LABORATORIES, INC.

/s/ Murray G. Crosby
Murray G. Crosby, President

MGC/he
Enc. (1)

Copied at NAEB Hqs. on Nov. 24, 1954

November 12, 1954

Mr. Murry G. Crosby, President
and Research Director
Crosby Labs, Incorporated
Box 233, Robbins Lane
Hicksville, L.I., New York

Dear Mr. Crosby:

I was recently discussing the development of FM multiplexing with Mr. Coulton of the RCA Engineering Products Division, who told me you had done much of the development work. He also said that you had published an article in the July-August 1953 issue of Communication Engineering, covering this development; however the University of Illinois does not have this publication on file in its library.

If there are reprints of this article available, I would appreciate knowing where I might obtain one. I am investigating the possibility of the use of FM multiplexing in a network of educational FM stations.

Any information you may be able to furnish will be appreciated.

Yours very truly,

Cecil S. Bidlack
Television Engineer

CSB:cp

file

November 12, 1954

Mr. Paul B. Rickard, Director
Radio and Television
Wayne University
Detroit 1, Michigan

Dear Mr. Rickard:

Your letter of January 29, 1954 to Dr. Skornia was forwarded to Mr. Menzer, Chairman of the Engineering Committee who gave it to me last July. Only recently when I was in Camden at RCA, have I had an opportunity to get some first hand information on the problem of FM multiplexing.

I was introduced to a Mr. Coulton of the RCA Engineering Products Division, in charge of new product development, who had witnessed a demonstration of FM multiplexing. They have had inquiries from networks and other commercial broadcasters regarding the development of FM multiplexing for the transmission and reception of programs of binaural sound on a single channel.

Obviously this is quite a different problem than the multiplex network which you envision where the FM station would be transmitting different programs. Mr. Coulton says the transmission of two different programs is entirely feasible; however additional filtering would be necessary to keep down cross talk between channels.

As far as the cost of the equipment is concerned, Mr. Coulton made a "rough" estimate that the necessary equipment for multiplexing might cost $5000 per station with an additional $2000 worth of test equipment to maintain the necessary tolerances. He would not make any commitment on the cost of the receiver for such a system. In any event the cost of multiplexing transmitters and associated receivers would depend to a great extent upon how many such units were manufactured.

As regards a nationwide network, it is obvious that while it might be possible to maintain bandwidth on such a system the problem of signal to noise ratio would be a very real one if we were to attempt a transcontinental network. A look at the radio coverage map of NAEB members would indicate the possibility of a Midwest network extending from Ohio through Indiana, Illinois, Wisconsin, Minnesota, Iowa and possibly to Kansas and Oklahoma. A New England network might also be a possibility but from there on, the separation between stations is such that I do not believe networking would be feasible.

In view of the capital outlay required to accomplish multiplexing at the present time, perhaps it would be well to survey the present Wisconsin educational FM network. We could also investigate the results obtained by some of the commercial regional FM networks used to transmit sports broadcasts, such as the Standard Baseball Network and also the Carling's Football Network which originate in Cleveland, Ohio. These sports networks however do not provide the superior broadcast quality you mention since they employ Class "D" telephone circuits to accomplish some of the longer hops.

I realize that all the above is rather vague, however it does indicate that we have not entirely forgotten your request. If you wish, I shall try to get further information on transmission over FM networks, not necessarily multiplexed, which on a regional or state basis might provide the benefits outlined in your letter. Obviously there would be programming and coordination problems to be solved in addition to the technical ones.

Yours very truly,

Cecil S. Bidlack
Television Engineer

CSB:cp

CC: Harry Skornia
Carl Menzer

February 2, 1954

Dr. Harry J. Skornia
Executive Director
National Association of Educational Broadcasters
University of Illinois
119 Gregory Hall
Urbana, Illinois

Dear Dr. Skornia:

Your letter arrived while Mr. Menzer is on a long-delayed vacation. He will attend to the matter upon his return at the end of this month.

Yours very truly,

Lee Eitzen
Program Director

LE:jes

NATIONAL ASSOCIATION OF EDUCATIONAL BROADCASTERS

NAEB

OFFICE OF EXECUTIVE DIRECTOR

UNIVERSITY OF ILLINOIS
119 GREGORY HALL
URBANA, ILLINOIS

January 29, 1954

Mr. Carl H. Menzer, Director
Station WSUI
State University of Iowa
Iowa City, Iowa

Dear Carl:

Herewith a letter from Paul Rickard with a proposal of a project which makes sense to me. I hope your Committee may give it consideration, and that we may have your recommendation on it.

Because of our secretarial load, I am sending you the original letter from Paul. I hope that, as soon as you have been able to consider it, you will let us know your reaction.

Sincerely,

Harry

Harry J. Skornia
Executive Director

HJS:ms
Enclosure

cc: Paul Rickard

WAYNE UNIVERSITY
BOARD OF EDUCATION
DETROIT 1, MICHIGAN

COLLEGE OF LIBERAL ARTS
DEPARTMENT OF SPEECH

January 26, 1954

Dr. Harry Skornia
Executive Director
National Association of Educational Broadcasters
Gregory Hall
University of Illinois
Urbana, Illinois

Dear Harry:

You will recall that I discussed briefly with you at the last meeting of the Board the general problem of multiplexing and further that I talked with Keith Ketcham with regard to the advisibility of exploring the general idea. The reactions of Keith along with the reactions of my own engineering staff lead me to the following proposals:

I would like the Engineering Committee of the NAEB encouraged to conduct a preliminary discussion to determine if this committee wishes to recommend to the Board that funds be requested from some appropriate source to conduct an extensive engineering survey along the following lines:

1. A nation-wide engineering survey to determine the practicability of a national multiplexed network with or without the installation of additional transmitters.

2. A pilot experiment in the state of Michigan or in any other state that they might consider to be more appropriate to be operated during the time the national survey is being made.

In the event that such a request should come from the Engineering Committee, in the event that the Board of Directors approves the request for funds, in the event that these funds are forthcoming, and in the event that multiplexing ultimately develops either on a state, national, or regional basis - I would anticipate the following benefits to NAEB member as compared with the present NAEB tape network:

1. Greater economy
2. Superior broadcast quality
3. The opportunity of distributing live programs
4. The psychological advantage of a real educational

4. continued

network functioning with flexibility equal to a national commercial network or with broadcast quality superior to any network connected by telephone lines.

To the end of achieving the above, would you and/or Graydon communicate with the Engineering Committee as early as is practicable and would you also be kind enough to keep me informed with regard to progress. I am, of course, assuming that it is proper for this action to be taken through the Engineering Committee of the NAEB. If you do not believe this would be the proper procedure, would you notify me in this connection also.

Best personal wishes.

~~Very~~ truly yours,

Paul

Paul B. Rickard, Director
Radio and Television

PBR:mf

December 21, 1954

Mr. H. S. Renne
Technical Editor
Radio-Electronic Engineering
366 Madison Avenue
New York 17, N. Y.

Dear Mr. Renne:

Thank you for your letter of December 13 concerning the article on FM multiplexing which appeared in Communication Engineering.

I have written Mr. Crosby and before your letter arrived, he sent me a reprint of the article which I wanted so I will not need the photostats you mentioned in your letter.

Yours very truly,

Cecil S. Bidlack
Television Engineer

CSB:cp

RADIO-ELECTRONIC
Engineering

366 MADISON AVENUE, NEW YORK 17, NEW YORK
Telephone MUrray Hill 7-8080

December 13, 1954

Mr. Cecil S. Bidlack, Television Engineer
National Association of Educational Broadcasters
14 Gregory Hall
Urbana, Illinois

Dear Mr. Bidlack:

Thank you for your letter of November 23rd requesting information on an article on FM multiplexing which appeared in the magazine "Communication Engineering."

Apparently, the article referred to in your letter is the article entitled "Binaural Sound on One Channel," by M.G. Crosby. Unfortunately, we do not have copies of the issue in which this article appeared, but we can provide you with photostats of the article at cost. Such photostats run about $1.00 a page and the article consists of 3 pages.

Another possibility would be to contact the author of the article

Mr. M.G. Crosby
Crosby Labs., Inc.
Box 233
Robbins Lane
Hicksville, Long Island, New York

since he may have reprints or other information on this subject.

If you wish the photostats under the conditions outlined above, we will be happy to send them to you.

Very truly yours,

RADIO-ELECTRONIC ENGINEERING

H. S. Renne

H.S. Renne
Technical Editor

HSR:rj

CECIL S. BIDLACK

'53-4

A Reprint From

Communication Engineering

July-Aug. 1953 MILTON B. SLEEPER, *Publisher* Price 65 Cents

Established as FM 1940

FIG. 2, LEFT: SINGLE-SIDEBAND RECEIVING UNIT WITH POWER SUPPLY. FIG. 6. DIVERSITY COMBINER

Long-Range Communication With

Single-Sideband Diversity Units

TRANSOCEANIC COMMUNICATION CAN BE ACCOMPLISHED DEPENDABLY WITH SINGLE-SIDEBAND DIVERSITY EQUIPMENT — *By* MURRAY G. CROSBY*

ONE of the heaviest long-range communication traffic loads in history occurred during the time of the recent coronation ceremonies in England. Wide use was made of single-sideband equipment, which performed very creditably. Dependable transoceanic reception of standard traffic and photo transmissions was achieved with Crosby triple-diversity single-sideband systems, used by RCA Communications and Press Wireless. This relatively new equipment is described in the following pages.

Advantages of Single-Sideband: A primary reason for the increased use of single-sideband systems is that they yield an important saving in frequency bandwith requirements. This is of great importance because of the rapid growth in international radio communication, which is worsening the already-severe congestion in the short-wave channels.

In addition to the basic advantage of economical frequency utilization, single-sideband systems permit a 9-db effective power gain as compared with double-sideband AM systems. This improvement factor is of considerable significance, particularly in multi-channel communication circuits and in international broadcast services where quality of signal must be preserved in order to meet basic performance requirements.

Single-sideband receiving techniques have significant value in eliminating certain types of interference even when employed with double-sideband transmission systems. A single-sideband receiver can operate in the presence of interference which may fall within the range of one sideband, but not in the range of the other. Sideband selection in such a case can get rid of the interference completely. This, of course, is a real advantage in view of the present severe band overcrowding and international jamming. At the present time, as a receiver is tuned to various signals in the HF frequency range, it is a very rare occurrence to find one signal free from interference on both sidebands, and which could not be improved by using one sideband alone. Thus, there is an obvious advantage in the use of single-sideband receivers in any communication system, even though the receiver may not be utilized in receiving signals transmitted by the single-sideband method.

Single-Sideband Adaptor: In a single-sideband system, a conventional short-wave communications receiver is employed to select and amplify the desired radio-frequency carrier and its modulation components. Fig. 1 is a block diagram of the adaptor for converting such a receiver to single-sideband operation; a view of the combined receiver (in this case, a Hammarlund SP-600JX) and adaptor is given in Fig. 2.

By means of a coaxial-cable connection with the IF output circuit of the receiver the selected carrier signal, at intermediate frequency, is fed to the converter of the adapter. Here the carrier is heterodyned with a second signal from a high-frequency oscillator, under precise automatic frequency

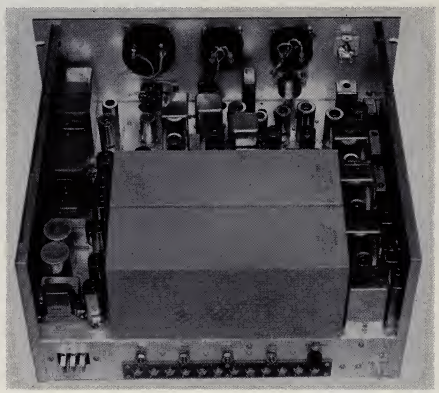
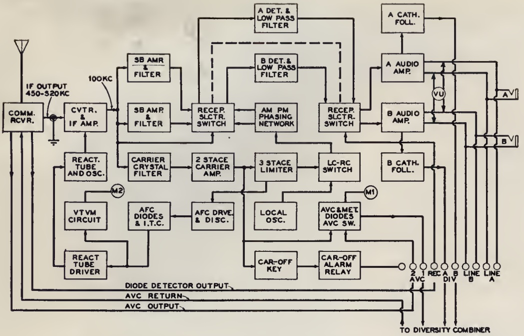
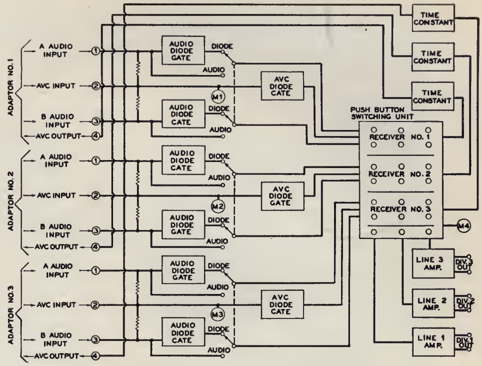


FIG. 3. SINGLE-SIDEBAND RECEIVER ADAPTOR. NOTE CRYSTAL FILTERS

*President, Crosby Laboratories, Inc., Hicksville, Long Island, N. Y.





FIGS. 1 AND 7. FUNCTIONAL DIAGRAMS OF THE ADAPTOR AND COMBINER UNITS

control, to produce a new intermediate frequency of 100 kc.

The 100-kc. IF signal, with modulation components, is amplified and applied to upper and lower sideband filters having pass-bands from 100 kc. to 106 kc. and from 94 kc. to 100 kc., respectively. These filters can be seen in Fig. 3, which is a rear view of the adaptor. Responses of the filters are shown in Fig 4. The 100-kc. signal is applied also to a sharply-tuned crystal filter with a passband of 20 cycles, which removes the sidebands as shown in Fig. 5. This is fed to a two-stage carrier amplifier, in which the carrier amplitude is adjusted to an optimum level, as required in compensating for carrier reduction at the single-sideband transmitter. From this point, the amplified carrier is applied to a three-stage limiter, a pair of diodes which supply AVC and carrier meter voltages, and a keying amplifier which forms a part of a carrier-off alarm circuit.

From the three-stage limiter the carrier, reconditioned and exalted by the filter, carrier amplifier, and limiter, is applied to one side of a Reconditioned Carrier-Local Carrier selector switch identified as the LC-RC switch in Fig. 1. A locally-generated 100-kc. carrier from a crystal oscillator is applied to the opposite side of the LC-RC switch. Thus, a choice of reconditioned exalted carrier or local carrier for single sideband reception is available. From the LC-RC switch, the selected carrier is fed to an AM-PM phasing network. This is used in establishing the proper phase relationship between the sidebands and the selected carrier in amplitude-modulated double-sideband signal reception and in phase-modulated double-sideband signal reception.

The reconditioned or local carrier and the sideband signals from the two sideband filters are applied through a reception selector switch to individual detectors for channels A and B. Here, exalted-carrier detection is provided by a triple-triode product-type detector; this unique circuit eliminates harmonic and cross-modulation distortion caused by selective fading of the carrier component. The audio signals in each channel are then applied, through low-pass filters, to separate audio amplifiers associated with the two channels.

The reception selector switch provides for operation with virtually any method of reception. When the sideband filters are switched into the circuit, single-sideband exalted-carrier reception is provided. Either the upper or lower sideband of a conventional double-sideband AM transmission can be selected individually, and the signals applied to separate detectors and audio amplifiers, or both sidebands of a twin-channel multiplex transmission can be received concurrently, with the individual signals being applied to the respective detectors and audio amplifiers. When the signals are selected directly from the 100-kc. IF amplifier and the AM section of the phasing network, exalted-carrier double-sideband AM reception is obtained. When the PM section of the phasing network is used, exalted-carrier reception of phase modulated double-sideband signals is provided. When a connection is made directly to the diode output of the communication receiver, conventional double-sideband AM reception as provided by the basic receiver is possible.

100-kc. carrier voltage from the first stage of the three-stage limiter is applied to an amplifier driving a crystal discriminator, which produces an output voltage proportional to small frequency deviations from the mean frequency of 100 kc. This voltage is rectified by the AFC diodes. The DC error voltage obtained is impressed on the grid circuit of a reactance-tube driver, which contains a storage capacitor for Infinite Time Constant (ITC) operation. In the event that the IF carrier falls below a predetermined level in the ITC circuit, the AFC diodes are disabled. When the carrier reappears, normal AFC action is restored. This protects the reactance tube and oscillator from spurious control by un-

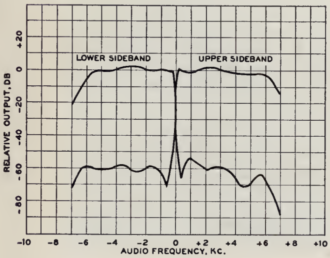


FIG. 4. COMPLEMENTARY RESPONSES OF SIDEBAND FILTERS IN AN ADAPTOR

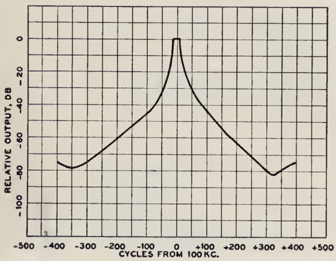


FIG. 5. PERFORMANCE OF THE CARRIER SEPARATION CRYSTAL FILTER

desired signals or noise during intervals when the desired radio carrier drops below a designated threshold strength. At the same time, while the AFC voltage is removed, the residual charge on the storage capacitor of the reactance-tube driver remains at a substantially constant potential over periods of several minutes, thus holding or freezing the high-frequency oscillator at a frequency in close proximity to its last-corrected frequency. In normal operation, when carrier is present, the AFC circuit is relatively immune to high noise peaks or interference from jamming signals because of the protection afforded by the crystal filter, limiter, and crystal discriminator.

The 100-kc. signal voltage, after passing through the crystal carrier filter and the carrier amplifier, is rectified by an AVC diode. Normally, it is then applied to the AVC circuit of the communication receiver to provide protection against interference which might otherwise gain control of the AVC system. When used in a diversity system, the AVC voltage is applied to the diversity combiner, described below, and is afterward fed back to the communication receiver. A switch permits the AVC system to be controlled either from the filtered and rectified carrier alone, as above indicated, or from the total rectified signal and sidebands, which is advantageous for tuning purposes. The carrier meter furnishes visual indications of signal level and proper tuning.

Diversity Combiner: The operating principle of the diversity combiner, shown in Fig. 6, is that of a diode gate controlled by the rectified signal so that the gate selects automatically the audio output from the receiver having the strongest rectified carrier or total signal.

The audio signal from each channel of each receiver, Fig. 7, is fed through its individual diode gate to a common load resistor, incorporated in a push-button switching unit. DC voltage from the AVC circuit of each receiver is fed to the respective audio diode gates of each channel through isolating resistors, as shown in the diagram, and directly to an AVC diode gate. The diode gates act as controlled resistances, each of which has a low value when the bias from the rectified signal is high, and a high value when the bias is low. The audio voltage fed through the controlled resistance to the common load resistance, therefore, is selected primarily from the receiver with the strongest rectified carrier or total carrier at any given moment.

The selected audio voltage in each audio channel is applied to one of the audio amplifiers in the combiner, and the DC voltage from the strongest signal is fed back to the individual receivers

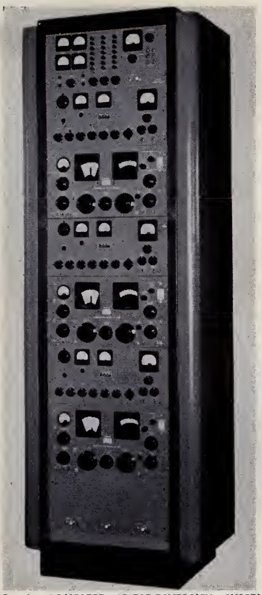


FIG. 8. COMPLETE TRIPLE-DIVERSITY SYSTEM

through selected time-constant networks to apply common AVC. Direct addition of the audio outputs of each receiver can be obtained in lieu of diode-gate selection when the DIODE-AUDIO switch is in the AUDIO position.

The AVC voltages in the receiver channels are applied to vacuum-tube voltmeters, shown in Fig. 7 as M1, M2, and M3, to provide indications of signal strengths. VTVM M4 is furnished to indicate logarithmically the combined signal strength. Audio signal level in any channel can be measured by means of VU meter incorporated in the combiner but not shown in the diagram.

Conclusion: By means of the push-button switching unit, which contains the common-load resistors and dummy-load resistors, any receiver channel can be connected individually to its dummy load to feed any of the three audio line amplifiers; alternatively, signals from any combination of two or three receivers connected in a diversity arrangement on a common load can be fed to any one of the audio amplifiers. This provides full flexibility of interconnection between the various receiver channels and the three audio amplifiers, so that they can be set up in any conceivable arrangement of triple-diversity, dual-diversity, or single-receiver systems with a choice of either sideband from any receiver or combination of receivers. Such flexibility ensures dependable operation under virtually any combination of operating requirements

FIG. 9. POWER SUPPLIES FOR THREE ADAPTORS

and atmospheric conditions. Fig. 8 shows a complete triple-diversity equipment rack: the diversity combiner occupies the top space; under it are three groups of adaptors and receivers; finally, at the bottom, a power supply panel furnishes power for the adaptors. A rear view of this panel is given in Fig. 9.

EQUUIPMENT UNDER R.C.A. PATENT LICENSE

THE COVER PICTURE

Almost unappreciated during the scramble of the TV networks to get films of the Coronation was the fact that radio and newspaper coverage was solid, in spite of magnetic storms; radiophotos and detailed accounts of the proceedings come uninterrupted over the facilities of Press Wireless and RCA Communications. Anthony Hilferty of Press Wireless is shown on the cover operating Crosby single-sideband triple-diversity equipment which was used at Baldwin, Long Island to pick up the transoceanic broadcasts. This setup is described in detail beginning on pages 29 and 32.

Sum-and-Difference Multiplexing for

Preprinted from
TV & Radio Engineering
August & September, 1953

Binaural Sound on One FM Channel

WITH SUM-AND-DIFFERENCE MULTIPLEXING, TWO HIGH-FIDELITY CHANNELS HAVING GOOD SIGNAL-TO-NOISE RATIOS ARE OBTAINED — *By* M. G. CROSBY*

ABSTRACT

The techniques of applying additional channels to a standard frequency-modulation transmitter, by means of a superaudible subcarrier in the range of frequencies between 20 and 75 kc., are briefly reviewed with respect to the circuits which may be applied, the cross-modulation problems, and the signal-to-noise ratios obtained.

A new method of applying the two channels of the binaural system is described, in which improved signal-to-noise ratios are obtained for the subcarrier channel, which normally has a poorer signal-to-noise ratio than the main channel. The system also has advantages with respect to balancing the noise received on the main and subcarrier channels, and provides non-degraded monaural reception.

IT is the object of this paper to point out some of the problems involved in using multiplex techniques to apply both channels of a binaural sound system on a single FM carrier. The basic system, which can be adapted either to an FM broadcast transmitter or the sound channel of a television transmitter, employs a superaudible subcarrier in the range of frequencies between 20 and 75 kc. This subcarrier is frequency-modulated by the second binaural channel. Experiments have shown that it is possible to apply such a superaudible subcarrier without appreciably affecting the signal-to-noise ratio of the main channel, and with negligible cross modulation between the two channels.

FM multiplexing is not new. E. H. Armstrong, in his early FM work, reported the application of telegraph, facsimile, and program material on multiplex channels. Multiplex Development Corporation worked with facsimile multiplex on the Rural Radio Network in New York State and demonstrated various multiplex applications including binaural sound. The concern of this paper is the particular method of applying the two channels to the multiplex system.

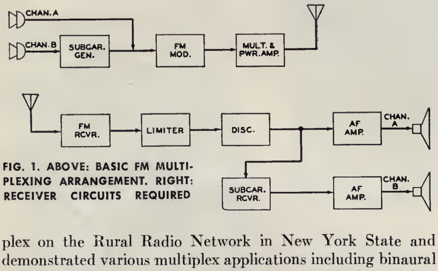
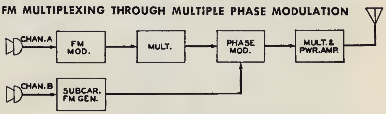


FIG. 1. ABOVE: BASIC FM MULTIPLEXING ARRANGEMENT. RIGHT: RECEIVER CIRCUITS REQUIRED

Basic System: Fig. 1 shows the usual multiplex system arrangement. The FM modulator stage must be broadbanded to accept modulation frequencies up to 75 kc. This permits the application of a subcarrier, which may employ a carrier frequency of approximately 45 kc. frequency-modulated approximately ± 15 kc. One of the binaural channel inputs is applied to the main modulator in the conventional manner, and the other modulates the subcarrier generator. The maximum modulation of the main channel and the subcarrier channel is usually determined by cross modulation problems. However, values of 50% modulation on both channels, such that the main channel has a frequency deviation of 37.5 kc. applied from binaural channel A, and the subcarrier channel produces frequency deviation of 37.5 kc. from binaural channel B, have been used successfully. It is desirable to apply as much modulation from the subcarrier as possible, since this channel has the poorer signal-to-noise ratio.

FIG. 2. FM MULTIPLEXING THROUGH MULTIPLE PHASE MODULATION



At the receiver, the main channel is detected in the usual manner, and a subcarrier receiver is connected to the output of the FM detector system ahead of the de-emphasis network. A high-pass filter may be employed in the subcarrier receiver to reject the main channel. The high-pass filter is followed by the usual limiter and discriminator system to detect the frequency modulation on the subcarrier.

Another means of applying the subcarrier modulation is shown in Fig. 2. This system employs a form of multiple phase modulation[1] applied by successive stages, so that the resultant modulation is the sum of the separate modulations. Use of this principle for subcarrier modulation is described[2] by E. H. Armstrong.

This arrangement, making use of an auxiliary phase modulator, has the advantage that it can be readily employed with existing transmitters. Also, cross-modulation and transmitter noise problems are less severe. If the system of Fig. 1 is used, in which the main frequency modulator is merely broadbanded to accept the higher subcarrier modulation frequencies, the cross modulation introduced by that modulator must be kept extremely low. In addition, certain FM transmitters of the phase-shift type begin with a carrier frequency so low that it is quite near the highest modulating frequency applied by the subcarrier. It would be questionable whether those FM modulators would be capable of accepting modulation input extending to 75 kc.

Signal-to-noise Ratio: Fig. 3 shows the signal-to-noise ratio characteristics obtained at the output of the FM discriminator in the main channel of the FM receiver. The noise at this point has the familiar triangular spectrum characteristic of a frequency-modulation system. The output of the main channel applied to the de-emphasis network is the spectrum OAB. The de-emphasis network reduces this noise to approximately the area given by the spectrum ODCB. In this way the usual high signal-to-noise ratio is obtained on the main channel.

It will be noted that the subcarrier, which may be at

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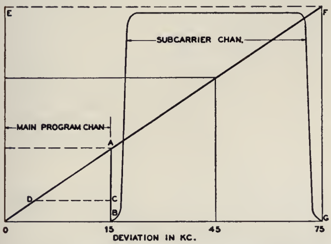
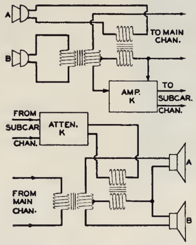
[1] M. G. Crosby, U. S. Patent No. 2, 104, 318, Jan. 4, 1938.
[2] U. S. Patent No. 2, 630, 497, March 3, 1953.

approximately 45 kc., is located quite far up in the triangular noise spectrum. The level of noise fed to the subcarrier receiver channel is almost as high as the AM noise, which would be represented by OEFG. The subcarrier channel, therefore, has a handicap which becomes greater as the subcarrier is made higher. Some improvement may be obtained by the use of frequency modulation pre-emphasis and de-emphasis, but after all expedients have been used to improve the signal-to-noise ratio of the subcarrier channel, it is still as much as 40 db poorer than that of the main channel.

Such a signal-to-noise ratio distribution in a transmission system for binaural sound departs considerably from what would be classified as the ideal system. The binaural system is only as effective as the poorest channel. Therefore, a system which has an excessively high signal-to-noise ratio on one channel has its transmission range limited by the transmission range of that channel. This makes satisfactory reception possible only in areas of rather strong signal strength; as the signal becomes weaker, the background noise becomes louder in one channel of the binaural system in a rather annoying manner.





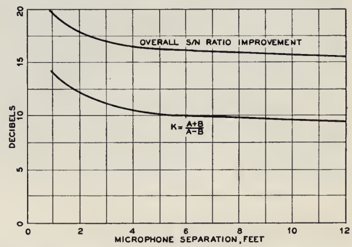


FIG. 3, LEFT: NOISE IN STANDARD SYSTEM. FIG. 4, CENTER: SUM AND DIFFERENCE MULTIPLEXING METHOD. FIG. 7, RIGHT: S-N RATIO IMPROVEMENT

Sum and Difference Transmission: An arrangement is shown in Fig. 4 which can overcome some of the usual difficulties experienced in binaural FM transmission. This involves feeding the sum of the outputs of binaural sources A and B to one channel, and the difference between the outputs to the other channel. The sum of A + B is fed to the main FM channel. This produces a level which may rise to a level approximately twice that of A or B alone. The difference between the two outputs, A – B, is fed to the subcarrier channel. This produces a level which may be considerably lower than that of A or B alone. The actual difference in level depends on the microphone spacing used when picking up the binaural material. For close microphone spacings, the difference output is considerably less than the sum output.

In order to obtain maximum utility when the difference combination is applied to the subcarrier channel, it must be amplified by a factor K so as to fully modulate the subcarrier channel. At the receiving end, the output of the subcarrier channel must then be attenuated by the same factor before the sum and difference outputs are recombined to obtain the separate binaural outputs. Thus, speaker A receives the sum of (A + B) + (A – B), or a quantity equal to 2A. Speaker B receives the difference between A + B and A–B, or a quantity equal to 2B. In this way, the two channels are separated.

The transformers in Fig. 4 are shown only for diagrammatic simplicity. In the case of the receiver especially, it would be much more economical to use phase-inverter techniques rather than transformers. When this is done, the only additional circuitry required at the subcarrier receiver for the sum-and-difference system is one tube and a few resistors. The subcarrier receiver uses about five tubes and may be arranged in the form of an adapter which is connected to the detector output of any FM tuner or TV sound channel. The adapter provides two outputs for the two loudspeaker channels.

One possible arrangment for such a system is shown in Figs. 5 and 6. A Browning FM tuner is in the top section of the cabinet; below this is a Crosby Stereosonic subcarrier receiver, whose two outputs are fed to the Fisher preamplifier-control units in the next two compartments. Audio power amplifiers are in the spaces below. An RJ speaker system is at each side of the cabinet.

Performance: The lower curve in Fig. 7 shows the difference in amplitude between the sum and difference binaural channels. This curve was obtained by comparing visually the amplitudes of the sum and difference combinations on a dual-channel oscilloscope. The binaural material which was used to obtain the data for this curve was obtained by Harold T. Sherman on experimental rehearsal recordings at Carnegie Hall. It will be noted that the difference between the two levels is greatest at the closest microphone spacing, 8 ins., at which it is approximately 14 db, and decreases to approximately 10 db as the microphone spacing is increased to 12 ft.

FIG. 5. THE AUTHOR WITH HIS STEREOSONIC FM RECEIVING EQUIPMENT

FIG. 6. COMPLETE BINAURAL RECEIVING SYSTEM WITH TWIN SPEAKERS

The overall signal-to-noise ratio improvement obtained with the sum-and-difference technique is very nearly equal to twice the ratio between the two levels. It can be evaluated as follows: The material fed to speaker A is a combination of the sum signal with the noise from the main channel, and the attenuated difference signal and subcarrier noise. The combination is given by

$$S_A + N = (A + B) + Nm + \frac{1}{K}[K(A + B) + Nsc], \quad (1)$$

where S_A = Signal in A channel
A = Microphone A signal level
B = Microphone B signal level
N = Noise in A channel
Nm = Main channel received noise
Nsc = Subcarrier channel received noise
K = Amplitude ratio between A + B and A − B

The signals A and B in equation 1 add arithmetically, and the noises combine in accordance with RMS addition, to give a total of signal and noise in the A channel equal to:

$$S_A + N = 2A + \sqrt{(Nm)^2 + (Nsc/K)^2}, \quad (2)$$

$$\text{or } 2A + Nsc\sqrt{(Nm/Nsc)^2 + (1/K)^2} \quad (3)$$

and the signal-to-noise ratio is

$$\frac{S_A}{N} = \frac{2A}{Nsc\sqrt{(Nm/Nsc)^2 + (1/K)^2}} \quad (4)$$

By the same process of development, using the difference combination of equation 1, the signal-to-noise ratio in B channel is:

$$\frac{S_B}{N} = \frac{2B}{Nsc\sqrt{(Nm/Nsc)^2 + (1/K)^2}} \quad (5)$$

Since the difference between the signal-to-noise ratio on the main and subcarrier channels is at least 20 db, so that $(Nm/Nsc) \leq 0.1$, and K ranges between 3 and 5, $(Nm/Nsc)^2$ can be neglected in comparison to $(1/K)^2$. Therefore,

$$\frac{S_A}{N} = \frac{2AK}{Nsc}, \quad (6)$$

$$\text{and } \frac{S_B}{N} = \frac{2BK}{Nsc}. \quad (7)$$

Either A/Nsc or B/Nsc represent the signal-to-noise ratio in the subcarrier channel as it would have been had not the sum-and-difference technique been used. Therefore it can be seen from equations 6 and 7 that the sum-and-difference technique results in two equal signal-to-noise ratios of value equal to 2K times the signal-to-noise ratio on the subcarrier channel. The upper curve in Fig. 7 shows the signal-to-noise ratio improvement for various microphone spacings. It can be seen that the signal-to-noise ratio on each channel of such a binaural multiplex system is between 15.5 and 20 db (depending on the microphone spacing) better than the signal-to-noise ratio of the subcarrier channel alone.

Obviously, it would be best to agree upon a fixed value of K, so that the attenuation could be fixed in the receiver. The value could favor the wider microphone spacings and still be good for the close spacings. The curves in Fig. 7 indicate that such a compromise value might be about 10 db, which produces an overall improvement of about 16 db. For the particular example of a signal-to-noise ratio of 65 db on the main channel and 25 db on the subcarrier channel, application of the sum-and-difference techniques results in two equal signal-to-noise ratios of 41 db. Fidelity on both channels is excellent, since the subcarrier receiver is flat out to 20 kc.

Aside from the improvement in signal-to-noise ratio of the subcarrier channel, the sum-and-difference technique has other advantages. Balancing the noises in the two channels produces a more natural reception, and the distracting effect of noise from one speaker only is avoided. Another advantage is that, since the main FM channel receives the sum of both binaural channels, better balance is obtained for the listener equipped only with a conventional receiver. This improvement becomes appreciably great for large microphone spacings. Finally, but not least important, is the ability to balance the gains of the two loudspeaker systems on noise. This can be done by detuning the receiver and adjusting the individual speaker gain controls until the noise appears to come from a point between the speakers.

Conclusion: With a binaural system, the listener has a natural tendency to seek out the source of the sound with his eyes. It is for this reason that the equipment cabinet in Fig. 6 was situated between the speakers. It is the author's opinion that the most logical object for the eyes to rest on would be a television screen; indeed, it appears that there should be even more applications for binaural sound in the field of television than in FM broadcasting.

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